From Bolts to Bytes: Paving the Way to Intelligent Manufacturing

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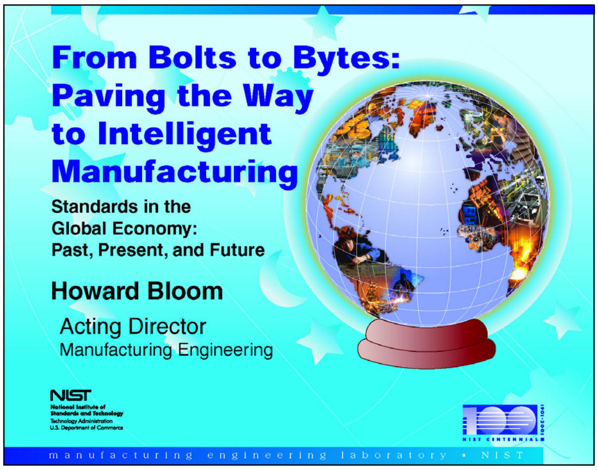
INTRODUCTION

Good Afternoon. The title of my talk basically reflects the trend in technology in manufacturing over the last 20 years. We at NIST have done our part to try to keep up with the concept of moving from bolts to bytes, and seeing how much information technology has influenced the ability of our manufacturers to be more productive. (Slide 1)



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I will specifically talk through a couple of examples, starting in the past and taking one into the present, and then look a little bit into the future to show how we go about satisfying the standards needs of industry through what we do. Let me just repeat the idea that our laboratory efforts in the Manufacturing Engineering

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Laboratory (MEL) are mainly oriented towards the discrete parts industry, to which we bring our core experience in dimensional and mechanical metrology, and now our growing expertise in advanced manufacturing for solving our industry problems. (Slide 2)

Just as some background—I don't expect you to read the details—but this is the portfolio of standards that we are working on, first from a national standpoint, and then from an international perspective. We work on a variety of committees in the area of dimensional and mechanical metrology. Also, because of the nature of the industry, we work on standards activities related to robotics, machine tools, and manufacturing interoperability, as well as how to put everything together, in both national and international committees. We at NIST are very dedicated to this work in order to produce the needed standards. (Slides 3 and 4)

National Standards Organizations with MEL Representation

American Measurement Tool Manufacturing Association (AMTMA)
Committee on Uncertainty and Rules on Conformance

American National Standards Institute (ANSI)
ANSI B212, Cemented Carbide (Cutting Tools)
ANSI S001, Acoustics
ANSI S002, Mechanical Vibration and Shock
ANSI S003, Bioacoustics
ANSI -C083, US TAG for ISO/TC108, Mechanical Vibration and Shock
ANSI -C084, US TAG for ISO/TC108/SC.03, Calibration of Vibration & Shock Measuring Instruments
ANSI -C100, US TAG for IEC/TC087, Ultrasonics
ANSI -C108, US TAG for ISO/TC184/SC01, Robot

Acoustical Society of America (ASA)
ANA -C001, Committee on Standards
ANA COS, Acoustical Committee of Standards

American Society of Mechanical Engineers (ASME)
ASME B1, Screw Threads
ASME B5, Machine Tools - Components, Elements, Performance, and Equipment
ASME B46, Classification and Designation of Surface Qualities
ASME B89, Dimensional Metrology
ASME C010, TAG to ISO TC 030, Measurement of Fluid Flow in Closed Conduits
ASME H213, Special Committee on Harmonization of Dimensional and Geometrical Product Specifications and Verification

American Society for Testing and Materials (ASTM)
ASTM E7, Nondestructive Testing
ASTM E28, Mechanical Testing
ASTM E41, Laboratory Apparatus
ASTM E42, Surface Analysis
ASTM F1, Metrology Committee

Electronic Industries Alliance (EIA)
EIA IE031, Numerical Control Systems and Equipment

Robotics Industries Association (RIA)
RIA R15, Robotics Standards

Society of Automotive Engineers (SAE)
SAE -C002, Lighting Coordination Electrical Systems Group

Semiconductor Equipment and Materials International (SEMI)
SEMI Standards
Metrology
Microlithography

US National Committee for IEC (USNC/IEC)
USNC/IEC TC029, Electro-Acoustics

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International Standards Organizations with MEL Representation

Conference General des Poids et Mesures (CGPM)
CGPM -C001, Consultative Committee on Mass and Related Quantities
CGPM CIPM, International Committee on Weights and Measures

European Accreditation Association (EA)
EA Dimensional Metrology Technical Experts Group

International Federation for Information Processing (FIP)
IFIP TC005, Computer Applications in Technology

International Electrotechnical Commission (IEC)
IEC TC029, Electroacoustics

International Organization for Standardization (ISO)
ISO TC 039, Machine Tools
ISO TC 108, Mechanical Vibrations and Shock
ISO TC 135, Nondestructive Testing
ISO TC 172, Optics and Optical Instruments
ISO TC 184, Industrial Automation
ISO TC 213, Dimensional & Geometrical Product Specifications and Verification

Object Management Group (OMG)
OMG-C002, Domain Technology Committee

Organization Internationale de Metrologie Legale (OIML)
OIML-C006, International Committee of Legal Metrology
OIML-TC09, Instruments for Measuring Mass and Density

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NECESSARY STANDARDS

I'm going to start on a theme now, which I will come back to a little later. We at NIST contend with the problem created by the great variety of standards that we must work on. How do we choose which ones to tackle, and how do we choose the level at which to work? The goal, of course, is to look at these standards and make sure that there is a level playing field, so that all industry can work hard, be productive and have an equal opportunity to make a profit. Two key elements associated with that are the decisions that we have to make. One is the expected impact—the financial impact, or the productivity impact—of having that standard in place. Let's not just produce a standard for the standard's sake; it must have an impact. (Slide 5)

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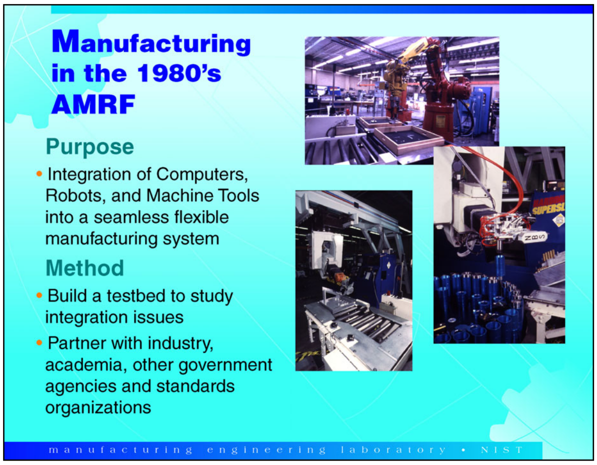
Secondly, why does NIST need to be involved? If industry can do it without NIST, we don't need to be involved. We need to limit ourselves to those cases where there is a true need for our core competence to be involved in getting a standard developed; I am going to come back to this a little later.

I will start with an example from the past to give you a flavor of the culture in our laboratory and how we decide to work on standards activities. In the late '70s, and in the '80s, there was a great deal of interest in flexible manufacturing and an expanded viewpoint of the "lights out" factories—that is, the intelligent factories—where you could store a lot of orders for products, put them on- line, and come back the next day, and the finished products would just be sitting there on the table waiting to be sold. (Slide 6)



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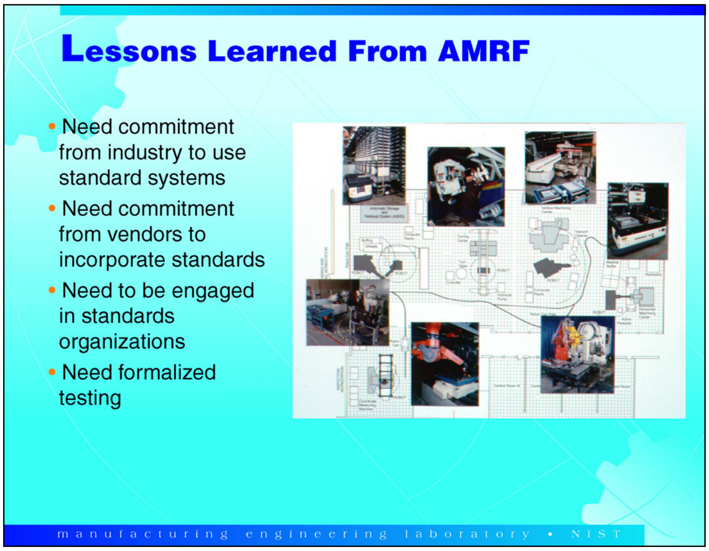
Things today still haven't yet reached that, but in the '80s, we put together a program called the Automated Manufacturing Research Facility (AMRF), where this interest in flexible manufacturing became the paradigm for how we were going to work on standards. The key thing was building a test bed. We were looking at the integration of computers, robots, machine tools, and measurement machines. We were concerned about how you could have effective standards to make sure that these systems worked well together, and that their performance was effective. You don't want to produce a standard unless you really see in a prototype environment that the standards are not going to inhibit your ability to manufacture, but are going to help it. So we put in place a test bed in our laboratory at NIST.

The second part, which is even more important—and whenever I use the term "we" in the rest of my talk, "we" will not refer only to NIST. "We" will refer to the fact that the only way we can really go about doing things is by working together with partners. We had a huge complement of industry coming to NIST and working with us. We were very involved with standards activities as we were developing the test bed. We must have had over a hundred companies, through the 10 years or so that the AMRF was operational, working with us to ensure that we were benefiting industry.

The test bed had seven work stations. Each workstation consisted of a robot, a machine tool, or a measurement machine, or a robocart or some kind of automated storage and retrieval system. We were looking at how to take the metrology that we had learned from our basic dimensional and mechanical metrology core competence, our knowledge of control systems, and



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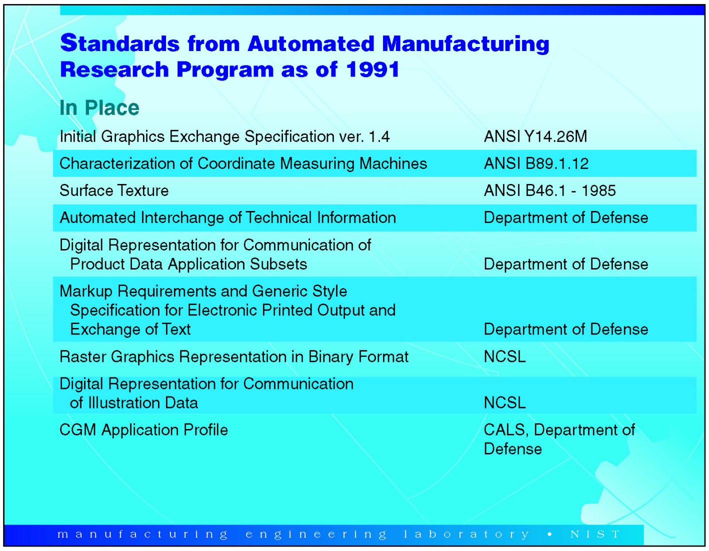
how to combine them together to anticipate the kinds of products industry was going to market in the '80s and '90s using flexible manufacturing. Then, through this combination we would develop the necessary standards and performance measures. One of the lessons that we learned from this was that industry has got to commit to using the standards. It doesn't do any good if an Standards Developing Organization (SDO) produces a standard if industry itself is not going to use it. I have heard that several times this morning—I think somebody was talking about ISO9000—if industry is not committed to it, it is not going to work. It is also not enough for industry to say that they are going to use the standard. Industry has got to tell the vendors that they will only buy products that conform to and satisfy the standards. Otherwise, the vendors are not going to build to the standards.

You need to be very engaged in the standards organization. In our case, we knew that the technologies were going to take 5 to 10 years to reach the market place, so we had time in those days, in the '80s, to work with the standards bodies and try to grease the wheels so that when the technology was there, the standards would be there, too.

The last point about the AMRF is that we did not do the job that we should have done in terms of formalized testing to ensure that when the standards were in place, the right kinds of testing protocols would also be in place, so that we could be sure that products would conform to the standards.



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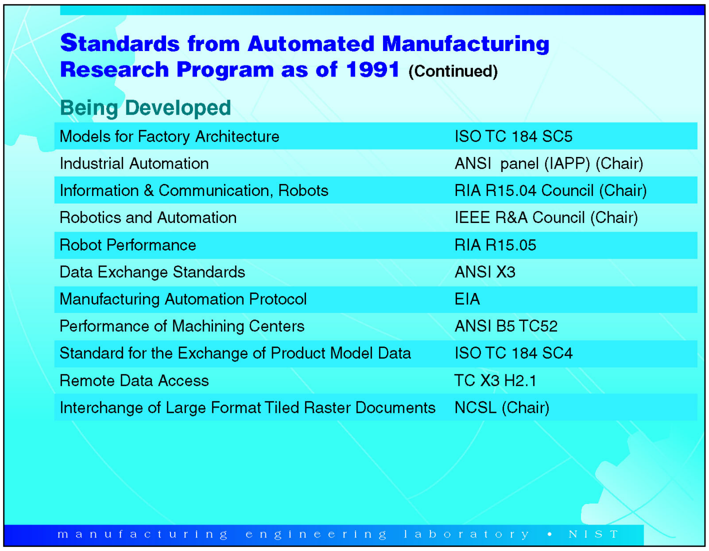
The slide (Slide 8) shows some of the standards that came out of the AMRF. This was published in ’91 when we were winding down the AMRF. Many of these were interface standards.

The first standard, the Initial Graphics Exchange Specifications (IGES), is an interesting standard because people are still buying IGES today. It is 20 years later and some people—especially in small companies—are still exchanging drawing data using IGES.

Some of these standards in the area of performance standards that we were working on in the ’90s have matured over the last several years. (Slide 9)

By this I mean, how do you know a robot is performing correctly, and how do you know that a coordinate measurement machine is doing what you want it to do? How do you know if a machine tool is performing according to specifications? We’ve spent a lot of time in the last 10 years, and will spend more in the future, as new technologies produce more and more intelligent robots and machine tools, to come up with more and more intelligent ways of measuring their performance.

Now, I want to emphasize that there is one thing you should remember from my talk. You can’t develop standards without a business case. That may sound a little funny coming from the government, but this is really the truth! (Slide 10)



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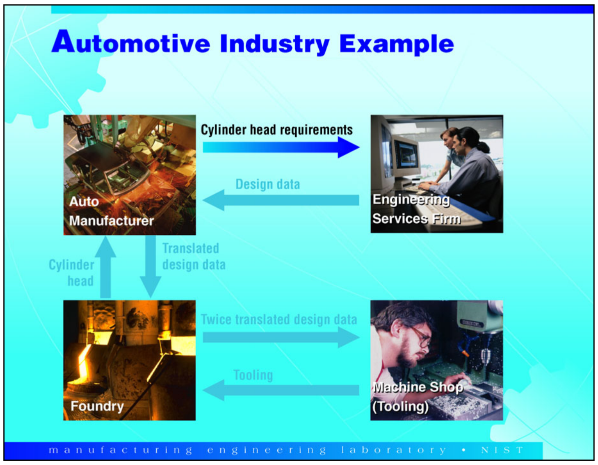
No standard is worth developing unless you can justify an economic benefit. I also heard this morning about how the number of people that companies put to work on standards committees is considered a cost. We shouldn't be doing it unless we can see at the other end that the standard is going to benefit the company. The one message to go away with is that you have to have a business case for developing a standard!

Now, I'm going to go quickly through a standard that my laboratory is probably very well known for, in terms of product data exchange. We have been working on this for 15 years, are still working on it, and may be working on it for the next 15 years. In that sense, it will certainly survive my lifetime here at NIST. But let me give you an example, and this will lead into what I mean by business case.

We became aware of an auto manufacturer, but I won't say which company it is. The auto manufacturer needed a new cylinder head design, and sent the requirements for it to an engineering service to come up with the design. (Slide 11)



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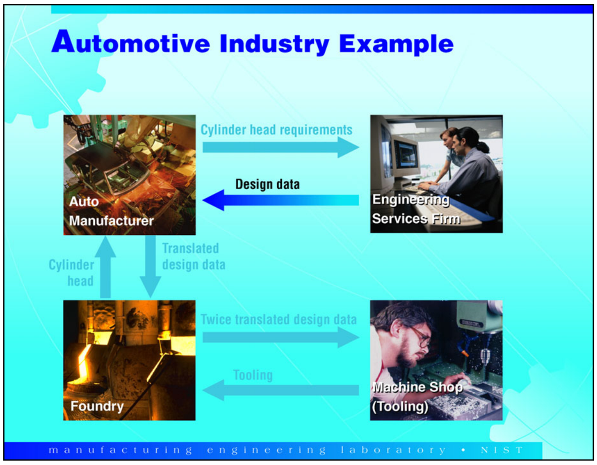
Okay. The engineering service took those requirements and used a computer aided design system with which they were very comfortable. They shipped the design data back to the automotive manufacturer. (Slide12) Okay. Now the automotive manufacturer needed to have that cylinder head made in a foundry, (Slide 13) but unfortunately the foundry did not have the same computer aided design system. So the manufacturer had to use its own computer aided design system to do some kinds of translations, then send that data down to the foundry. The foundry, of course, needed to have some tooling made, and, as it happens, it had its own computer aided design system. (Slide 14) It took this design data and shipped it to a tooling supplier in order to make the tools that it needed. The tooling company, of course, had a different computer aided design system, so it had to do some translations on its own. It did all of that, and then sent the tooling back to the foundry. (Slide15) The company was very happy. It had its tooling, could now manufacture the cylinder head, and so it sent the head to the automotive manufacturer.



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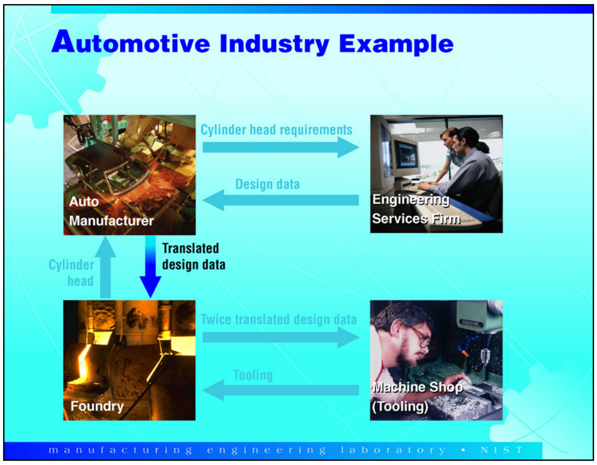

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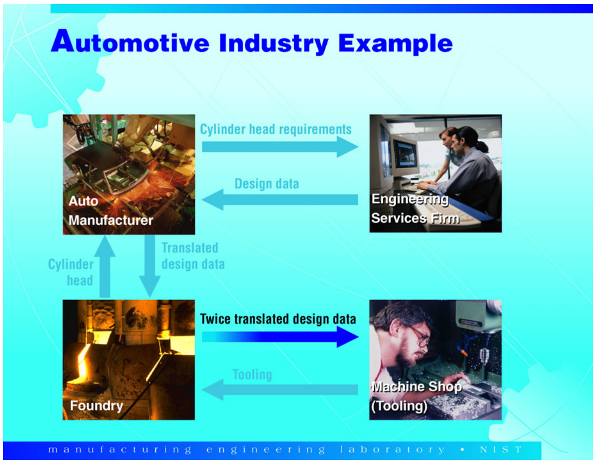

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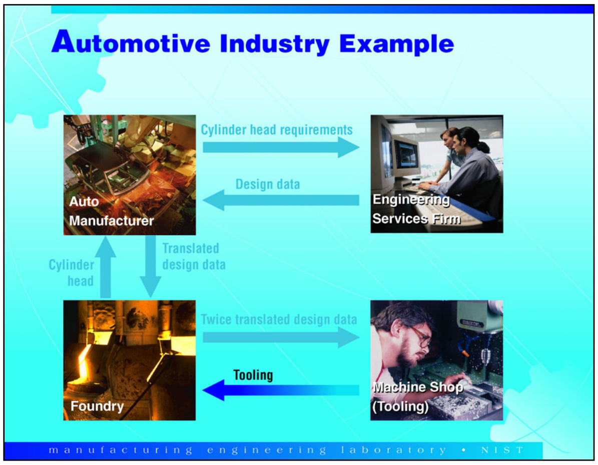

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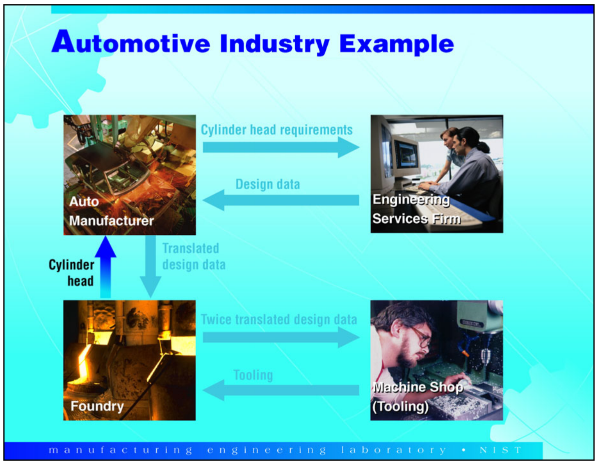
The cylinder head came back to the manufacturer, so you may think that everything is great? (Slide 16) Well, something went wrong. The cylinder head did not fit. What went wrong? Another message I want you to go away with is lack of interoperability. We have been talking a lot about interoperability in the Information Technology (IT) world.



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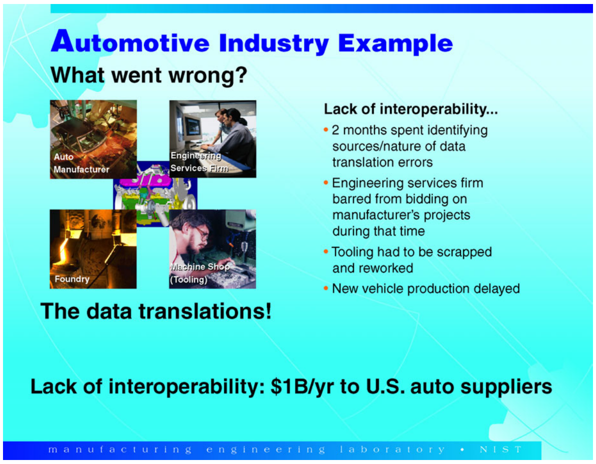
Two months were spent trying to figure out what went wrong in this case. By this point, the engineering service firm no longer was doing business with the automotive company. Tooling had to be scrapped. The problem is data translations—data translations—data translations. (Slide 17) We did a study on this, which we published last year. I think that almost every industry sector has taken this study and tried to apply it in terms of the sector's interoperability issues. Our study was done primarily with the Automotive Industry Action Group (AIAG), which showed that at the very least, there is $1 billion a year lost due to unsuccessful data translations because they weren't using a standard.



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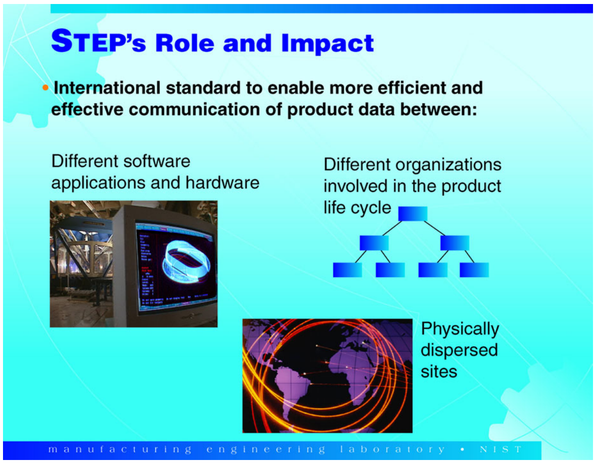
This is what I mean by a business case. Let me give just the first step for interoperability. The STEP is the STandard for an Exchange of Product model data. It is part of the ISO community and is in TC-184, which is the Industrial Automation Technical Committee, in Subcommittee 4. We have been working on it since 1984 and again the "we" here is 26 countries, and over 400 technical people who have been working year in and year out on the standard. The standard was meant to satisfy the problems of moving data between CAD systems and other systems that represent product data. It is supposed to work with different software applications, different places in the supply chain, and over dispersed sites. (Slide 18)



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Now, why was this standard a success? Number One, even though I am a government employee, it was industry driven. The government did not issue an edict saying we are going to have this standard. Industry said that we need to have a standard. There was a commitment by industry to use the standard. The push for a standard came from large companies, which could put the pressure on vendors who were developing the software to actually write the STEP translators. (Slide 19)

Another key element was that there wasn't a "Microsoft" already there with a system in place. There weren't a lot of Computer Aided Design (CAD) systems that could do the things that the STEP community envisioned, for we were looking 5 years beyond the existing CAD systems. There was no power conflict between two or three CAD companies urging use for one particular system—"Use my system as it is now as a standard." No one had the total system, so that made it easier to solve that problem. Finally, it was an international, rather than a national, effort. As I said, in the '80s the United States had IGES, Germany had its system, and France had its own thing. We decided that we weren't going to go that route. We, as an international community, decided that the only way to have an effective standard was to develop it internationally. Finally, we deliberately built conformance testing directly into the standard.

Here are some of the savings that you can see documented on some websites. In the United States, a standards organization called U.S. Pro Data managers the U.S. activities in STEP. You can also look on the ISO TC184/SC4 website. There have been tremendous savings. Pilot programs that companies have worked on have shown great savings. (Slide 20)

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On the other hand, companies have reported that they spent millions of dollarsone company spent $200 million maintaining 3 different CAD platforms—and if they had only had STEP they wouldn't have had to do that. So again, lots of benefits. Many companies are using STEP; it is for real! It has been in place now for six years. It is an evolving set of standards so that with each new application, a new standard comes about. (Slide 21)

But there are also problems that we learned with STEP. One was that we were trying to initially say was that one collection of data represented all the things that you might want to do with product data. This was a huge amount of data. It didn't work. (Slide 22)

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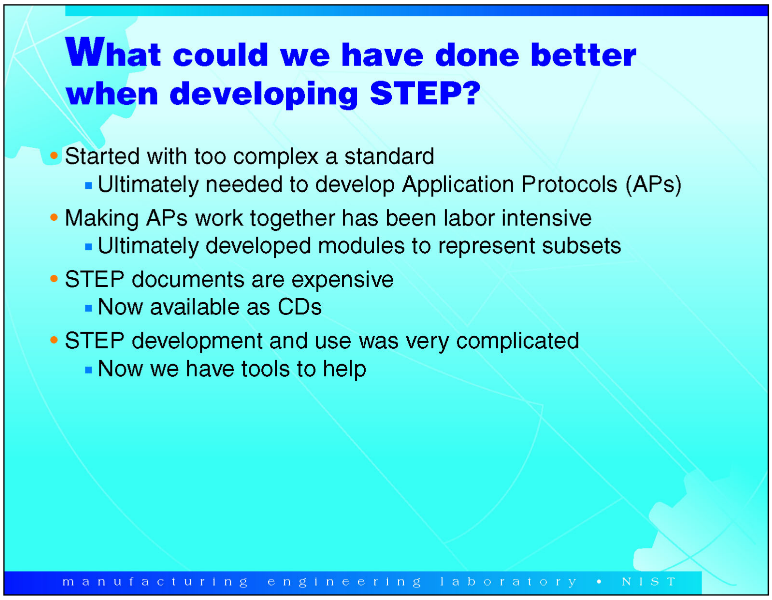

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We had to step back from that and decide that what we needed to create was what are called Application Protocols (APs). We would ask what we would need to do if we wanted to exchange finite element analysis data or geometry data. What if we do something for shipbuilding, instead of the automotive industry or process plants? So we developed a variety of AP's to make things smaller and more efficient. Now that caused a problem, and it was hard to integrate these protocols later. The solution now is to have lots of little modules that are independent of the application protocol so that you can build the application protocols out of these modules.

This morning we talked about the cost of documents. First of all, a typical STEP AP might be 5,000 pages. That is a lot of paper and it has been selling for $500 to $1000. Consequently, we are now going to CD's to get the costs down. Obviously, it would be great if STEP was free. The development itself is very complicated, so over the years we have had to develop a lot of tools. I think that whenever you have a complicated standard, you might want to consider in advance the kinds of technology tools that you could develop to make it easier to get the standard in place.

In this last minute or two, I want to look into the future. You have heard about flexible manufacturing, and taken a beginning look at interoperability.

What is the global economy going to look like over the next 20 years? (Slide 23) The Internet, or whatever comes after that, is going to transform manufacturing

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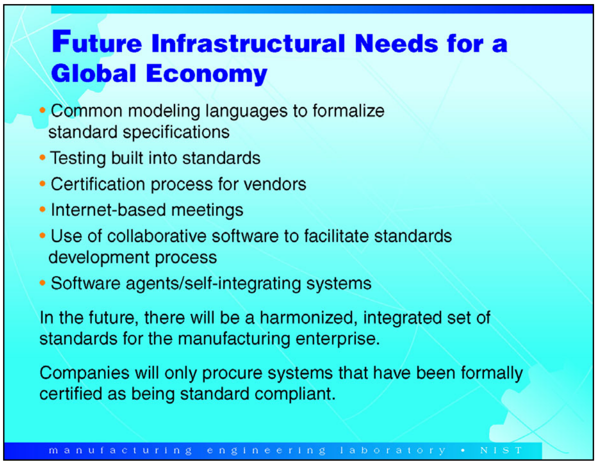
into totally distributed enterprises. We are beginning to see some distributed enterprises now. We are observing many mergers of companies internationally. Information is going to be deposited throughout the world: parts datawill be in one place, with process planning data and manufacturing data in other places, scattered throughout the world. Electronic commerce is going to get bigger and bigger, as talked about this morning. The need to do business, to negotiate, buy, and sell—all of this is going to be done remotely.

This will require interoperability, complete interoperability; the seamless, high fidelity exchange of data between different systems, without any loss or corruption, and seamless integration, because this is going to be computer to computer. Nobody is going to be looking at the data as it flies by, a hundred megabytes or whatever at a time.

What can we do to help the process from a viewpoint of standards? One thing is to look at common languages for the formal specifications of our standards. Many of our standards documents are written in English or in French, but there is some ambiguity in what you read. (Slide 24)



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In the STEP community, we developed the language called Express, a formal language that is very clear and unambiguous, so that you know exactly what the standard represents. From that, the testing was very simple to develop. In STEP there are standards called abstract test suites. It was very simple to do that because we had the unambiguous modeling language for the standard (Express) to be written in. In addition, we are going to need testing built into the standards in the future, so no standards should be issued without testing specified in it.

There will be certification for vendors. We really need to put pressure on companies and vendors not to buy anything that hasn't been certified, that you know will really work.

Another thing that people talked about this morning was the amount of time consumed in meetings. As

Mike Hogan and others discussed this morning, I believe that the interactive nature of standards meetings and the way the information is exchanged will in the future be Internet based meetings. We can't afford to travel around the world. It takes too long. We should be able to do more over the internet, and we ought to use collaborative software for gathering requirements for analyzing the standard, and for making decisions about the standard, rather than what we do now.

We will also see SMART systems, as in the area of manufacturing interoperability. These systems will be able to go out just as we do with fax machines today, query a system and figure out what language or what kind of semantics that system has, connect it to another system, and query that other system. It should figure out what kind of semantics and language another system has, connect the two together, and solve the problems of interoperability.

My dream of the future is that we will have a harmonized integrated set of standards for manufacturing, and companies will only procure systems that are formally certified.

Thank you.